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Commercial Environmental Forestry

Integrating trees into landscapes for multiple benefits

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CONTENTS

Overview

Commercial Environmental Forestry (CEF) promotes the wise use of forestry plantings and revegetation to achieve positive environmental outcomes in landscapes. The purpose of the three-year CEF research program was to provide landowners and resource managers with information and tools that enable them to make informed decisions about forestry establishment and revegetation. These predictive tools will only be of value if they are supported by robust science, to reduce investment risk and to provide confidence that the growth rates of forests and environmental benefits predicted will, in fact, be realised in the decades to come. It can also assess the likely past and future impacts on the environment of previous revegetation programs.

The core CEF research program addresses questions relevant to scales of regions and farms, such as:

- Where are the best places in the landscape and on farms to establish trees for environmental benefits, including intercepting salt moving into rivers and enhancing biodiversity?
- What are the best tree species to plant and what will be their likely rates of growth?
- By how much will streamflow be reduced and how can the impacts be minimised?
- What are the options through site and species selection, as well as forest management, to maximise growth, carbon sequestration and product value for economic benefit?

To answer these questions, CEF has focused on the following core areas:

1. Growth prediction and risk

To deliver maximum environmental and economic benefits, trees must survive and grow well. Research has produced calibrated models to predict growth and carbon sequestration of:

- Commercial forest species – *Eucalyptus cladocalyx* (sugar gum), *Corymbia maculata* (spotted gum), *E. globulus* (blue gum), *Pinus radiata* (radiata pine) and oil mallees – *E. kochii* (oil mallee), *E. polybractea* (blue mallee) and *E. loxophleba* ssp. *lissophloia* (smooth-barked York gum).
- Environmental plantings – mixed species, multi-layered, forests that often have been established for biodiversity enhancement by direct seeding, planting of tubestock, or by fencing of remnant native forest to encourage regeneration.

Additional research was undertaken on:

- The effects of management such as spacing and thinning on growth
- Development of a database for tree growth in Australia
- The potential impacts of climate variability and change on tree survival and growth.

2. Environmental services

The term "environmental services" refers to the outcomes from forests that are to the benefit of individuals and society. They typically include carbon sequestration, biodiversity, water quality, aesthetics and recreation. Some environmental service payments, such as for carbon credits, are emerging markets with investment schemes by state and regional governments essentially purchasing a desired future outcome. Research in CEF has focused on the impacts of forests on:

- Stream salinity
- Streamflow
- Carbon sequestration
- Biodiversity value.

3. Integration – The Scenario Planning and Investment Framework (SPIF) tool

The SPIF tool has been developed as part of the CEF program to enable users to explore the effects of alternative forestry and revegetation options. Research outputs were integrated into the SPIF tool which takes the spatial outputs from biophysical models and overlays them with GIS data for the region being studied. Users of the SPIF tool can set their own criteria for environmental outcomes and for the different types of forests and management impacts.

Applying the research

The outputs of research were applied in the South-West Goulburn Broken (SWGB) catchment, Victoria, as a desk-top case study. This region was chosen because a significant amount of salt is exported from this catchment, which overlies mostly local groundwater flow systems. Thus, this is a region where tree planting may have some effect on river salinity. Much of this saline area coincides with relatively high rainfall thereby offering the opportunity for reasonable rates of tree growth. Application of research in this region was supported by a high level of existing data, especially for groundwater salinity.

This summary technical report briefly describes the components of the various research projects and the types of outputs they have generated. It substantially expands on information contained within the 'Research' pages of the CEF web site. Final outputs and conclusions will be described in the final technical report, available later in 2006.

Growth Prediction and Risk

Reasonably reliable information and calibrated models are available to predict growth of major plantation species, such as *E. globulus* and *P. radiata*, in high rainfall areas. In contrast, there is relatively little information on the growth of commercial plantations in low-medium rainfall areas (500-750 mm), and almost no data for environmental plantings and remnant native forests in this rainfall zone.

This research gathered data on the growth of several commercial species, environmental plantings and natural regeneration and calibrated tree growth models for each system. Initially, the 3-PG model, developed by Dr Joe Landsberg and CSIRO for simple prediction of forest growth was used. In the final year of the project, the 3-PG+ version, developed by Dr Jim Morris (University of Melbourne), was used. Both models simulate important processes controlling growth but can be run using relatively simple environmental information.

Climate and soil data were also collated for the SWGB study area, so the growth model could be run for many locations. Together, the model and environmental data allowed potential tree growth to be estimated across the entire study area. These potential productivity maps were the major output from the growth work and are an essential part of the SPIF tool.

Some of the key questions for the growth prediction studies were:

- What are the best tree species to plant and what are their likely rates of growth?
- What are the growth rates of environmental plantings and natural regeneration of on-farm remnants?
- What are the risks posed by climate variability and change to successful establishment and growth of forests?

Growth modelling for species selection

Sugar gum and spotted gum

Species suitable for low-medium rainfall areas were reviewed and *E. cladocalyx* and *C. maculata* selected as species worthy of further attention. Both are capable of producing high quality timber, with *E. cladocalyx* being suited to sites with annual rainfall in the 400-600 mm range, whilst *C. maculata* is best suited to rather wetter sites (580-750 mm). Literature reviews were carried out to locate previous studies of growth and environmental conditions for the two species.

Growth and environmental data were gathered from 207 plots at 38 sites across south eastern Australia. In addition, trees from a range of sites were harvested to estimate above- and below-ground biomass. Allometric relationships were developed to relate biomass (Figures 1 and 2) to measures of stem diameter (DBH), as well as to other non-destructive measures of biomass. The 3-PG model was calibrated for *E. cladocalyx* and *C. maculata* using data from these trials and from the literature. Results showed that *C. maculata* grows slightly faster than *E. cladocalyx* in the low-medium rainfall zones.

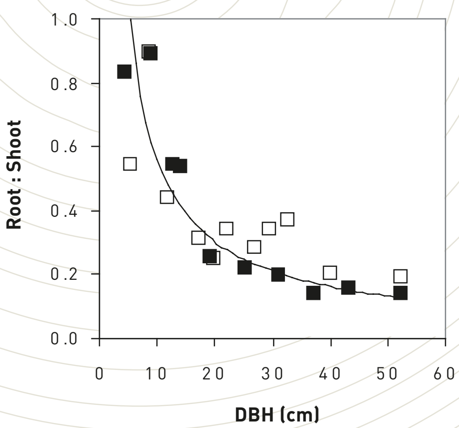


Figure 1. Relationship between stem diameter (DBH) and the ratio of root to shoot biomass for *E. cladocalyx* (■) and *C. maculata* (□).

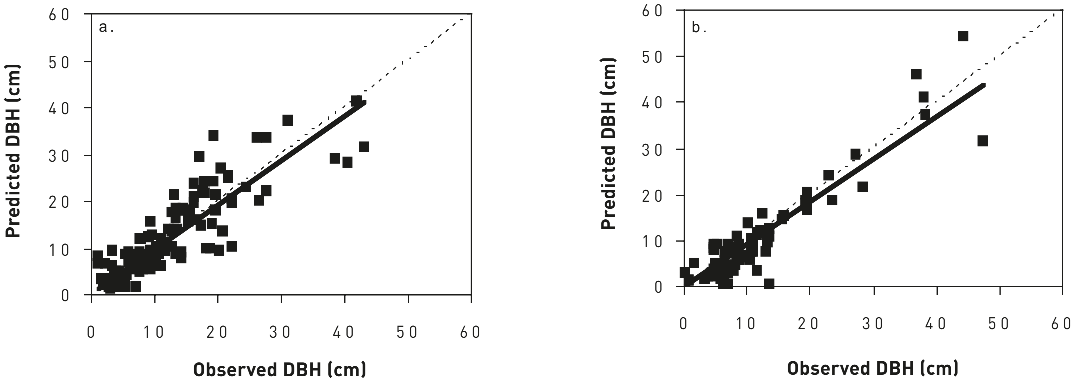


Figure 2. Relationship between predicted and observed stem diameter (DBH) across the (a) 135 datsets of *E. cladocalyx*, and (b) 80 datsets of *C. maculata*. Solid black line is the linear best-fit to observed data (when forced to pass through the origin) while the dashed line is the 1:1 isoline.

A climate and soils database was developed for the SWGB catchment. A 25 m resolution database of about 19 million points was initially developed to allow direct comparisons to be made with productivity predictions made by hillslope (FLUSH) modelling. However, later maps were produced at 100 m resolution to speed processing time. In the third year of the CEF program, both *E. cladocalyx* and *C. maculata* species files were recalibrated for 3-PG+.

As a result of this modelling work, maps of potential productivity were prepared for the target regions for use by the SPIF. Various management scenarios were also developed for *E. cladocalyx* and *C. maculata* plantations.

Blue gum and radiata pine

Despite emerging interest in species such as *E. cladocalyx* and *C. maculata* for drier areas, models of growth were also calibrated for the more traditional species of *E. globulus* and *P. radiata* (Figure 3). *P. radiata* is a softwood, generally grown on rotations of about 25-35 years for sawlogs. *E. globulus* is a hardwood, most often grown on short rotations of about 12 years for pulp, though a small proportion of stands are being managed on longer rotations for sawlog production. If available, high rainfall (>800 mm) sites are preferred for both species, though both have some potential in drier regions. *E. globulus* in particular has been widely planted in 600-800 mm, and sometimes drier regions.

These species were calibrated to enable the spatial prediction of growth rates and carbon sequestration for a wider range of species of interest. In particular, the study focussed on improving knowledge of the growth of these species in low-medium rainfall zones.

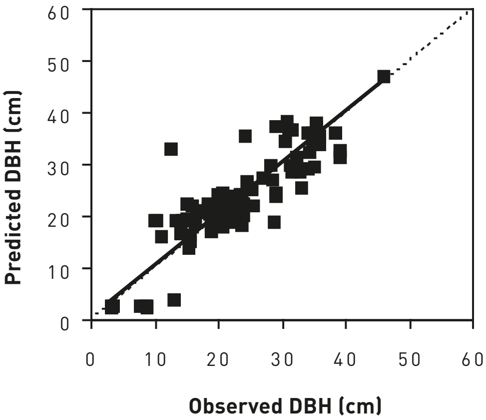


Figure 3. Relationship between predicted and observed stem diameter (DBH) across the 129 datasets of *P. radiata*. Solid black line is the linear best-fit to observed data (when forced to pass through the origin) while the dashed line is the 1:1 isoline.

In 2004-05, growth and environmental data were collected from 24 *E. globulus* sites within the SWGB catchment and a further 12 sites outside the catchment. There were few large-scale commercial plantations within the catchment old enough for sampling, so several small farm plantings were assessed. In 2005-06, a much larger dataset from *E. globulus* plantations in and near the SWGB was analysed. This was used for 3-PG+ model calibration, as previous studies had used data from medium-high rainfall areas.

For *P. radiata*, datasets on growth and biomass of tree components were collated from the literature and from previous work undertaken by Ensis in the Green Triangle, Tasmania and near Canberra to improve the prediction outputs.

The 3-PG+ model was calibrated for both *E. globulus* and *P. radiata*, and spatial surfaces of predicted growth created for the SWGB catchment. Results showed that *E. globulus* grows the fastest of all four plantation species calibrated. However, as *C. maculata* and particularly *E. cladocalyx* are more resistant to drought stress, these hardier species should be considered for lower rainfall sites.

Environmental plantings and remnant forests

Environmental plantings are mixed-species forests established for a variety of reasons including salinity mitigation, erosion control, stock shelter, carbon sequestration and biodiversity enhancement. While tools for prediction of growth are now reasonably well-developed for many commercial tree species, there is limited knowledge of growth of environmental plantings and no verified models for predictive purposes.

The environmental plantings and on-farm remnants studied included:

- Direct-seeded revegetation,
- Tubestock revegetation,
- Natural regeneration following stock exclusion,
- Remnant forest, and
- Farm forestry plantation (for comparison).

This study measured growth in mixed-species environmental plantings and compared them with native forest and single-species farm forestry plantations. Thirty-eight study sites were selected in low-medium rainfall areas of the Goulburn-Broken and North Central Catchments of Victoria. Detailed vegetation inventories were undertaken at each site. There was large variation in the density (stems ha^{-1}) and basal area (m^2 ha^{-1}) of trees and tall shrubs across sites, depending on the planting type and establishment method (Table 1).

Table 1 Variation in total stand density and total basal area of trees and tall shrubs across planting types. Values are means of 7-9 sites per planting/forest type.

Planting/forest type	Age range (years)	Mean age (years)	Stand density (trees ha^{-1})	Basal area (m^2 ha^{-1})
Farm forestry	5-12	9	659	10.5
Tubestock revegetation	5-18	9	455	4.8
Direct seeded revegetation	5-14	8	2464	7.0
Natural regeneration				
Mature trees	–	–	38	4.8
Regenerating trees & shrubs	9-30	18	1168	6.9
Total	–	–	1206	11.6
Remnant forest	>50*	>50*	610	20.5

* based on available local knowledge.

Allometric relationships for predicting above-ground biomass of tree and shrub species from measures of stem diameter were developed from biomass harvests. These relationships and site inventory data (diameter of each shrub and tree species, plot area) were then used to estimate total above-ground biomass and carbon sequestration of trees and tall shrubs. Data were used to calibrate the 3-PG+ model to predict growth (Figure 4) and carbon sequestration. Using these calibrations, spatially-explicit estimates of growth and carbon sequestration for different vegetation types were integrated into the SPIF tool. Results showed that of all the environmental plantings, those established by tube stock plantings grew the fastest while those established from natural regeneration grew the slowest.

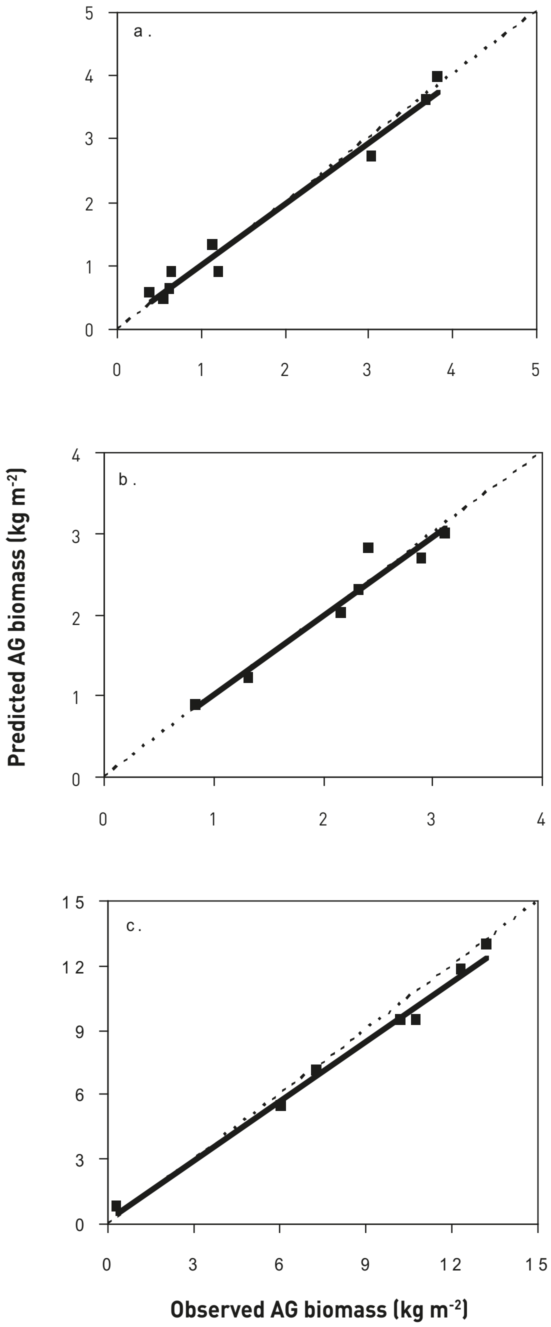


Figure 4. Relationship between observed and predicted above-ground (AG) biomass for: a) tubestock revegetation, b) direct seeded revegetation and c) natural regeneration. Data points represent individual sites (n = 7-9). Solid black line is the linear best-fit to observed data (when forced to pass through the origin) while the dashed line is the 1:1 isoline.

Oil mallees

Oil mallees have commercial prospects from production of eucalyptus oil, activated carbon and bioenergy. These species are grown in low rainfall (< 600 mm) areas of southern Australia. Oil mallees may also provide environmental benefits by using surplus water, therefore contributing to management of dryland salinity. This project is part of the CRC for Plant Based Management of Dryland Salinity, and was designed to develop a process-based model of oil mallee growth and water use, in order to predict the hydrological impact of oil mallees over different soil type, landscape unit and climate combinations.

In order to model growth and water use, 3-PG was parameterised for *E. kochii* from a detailed data set collected at a site in the northern wheat belt area of Western Australia. Research to date has been on tree physiology, growth and water use, focusing on responses to spatial and temporal variations in water supply. Water availability, particularly access to groundwater, has a large impact on water use (Figure 5), growth and allometric relationships of oil mallees. 3-PG parameter sets are also being produced for *E. polybractea* and *E. loxophleba* ssp. *lissophloia*. Spatial productivity surfaces and related environmental outcomes will be incorporated into the SPIF tool on a regional basis.

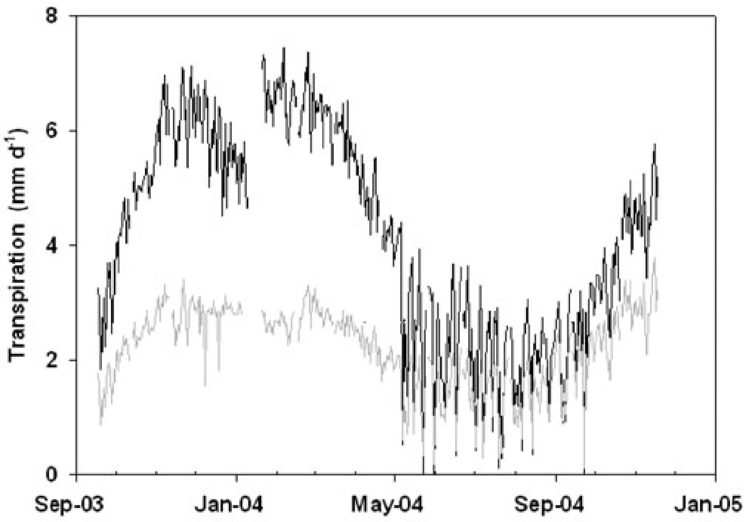


Figure 5. Transpiration of *E. kochii* at Coorow, WA, with (—) and without (—) access to groundwater.

TREDAT – A database for tree growth in Australia

A large number of farm forestry trials with varying objectives have been established in Australia over the past 15 years. A key challenge is to collate and synthesize information from these trials into a database that may be used as a basis for generic investigation of growth rates and for identifying factors controlling growth.

About 20 years ago the Australian Tree Seed Centre of CSIRO developed a database, called TREDAT, in collaboration with the Queensland Forestry Research Institute. This database links trial results for mainly Australian tree species with site characteristics (climate and soil) and management factors (such as tree spacing and use of fertilisers). A search of the TREDAT database for Australian trials with a minimum age of three years, resulted in an extract of about three thousand lines of data covering some 100 sites (Figure 6) and 180 tree species. These sites cover an annual rainfall range of 350-1800 mm. Measurement age ranged from 3-14 years. This project has enhanced TREDAT by including annual average climatic information for each site, as well as the interpolated actual climate for the growth period (from SILO Data Drill). A major task has been entering all available trial records, 'cleaning' the database, and calculating stand volumes from height and diameter data. Statistical analyses are underway on this large dataset.

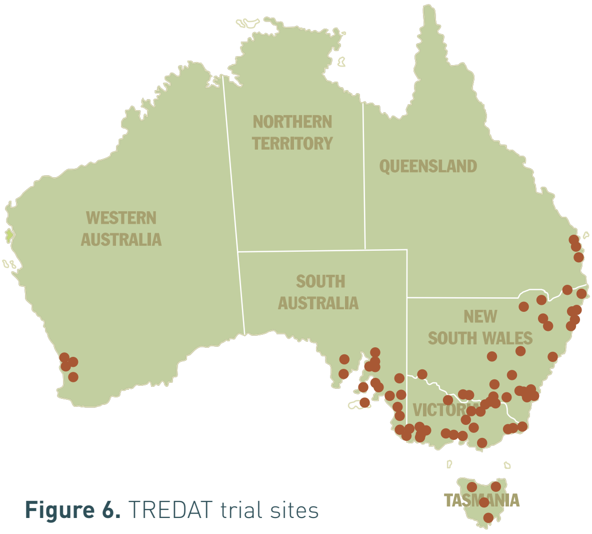


Figure 6. TREDAT trial sites

Benefits of this research include collation of a greater range of growth data in the database. Synthesis of data will result in new knowledge relating growth to environmental variables, and perhaps species and management effects. For example, a regression analysis including factors such as species and site conditions accounted for 85% of the variance in height growth. An additional benefit of TREDAT will be identification of sites where repeat measurements have been made and that would be suitable for further intensive monitoring and modelling.

Climatic variability and change

Given that environmental and financial benefits from forests established today will not realised for decades, the potential impacts of climatic variability and change are likely to be uppermost in the minds of investors as a significant risk. This is especially so where forests are established in already challenging areas.

Key issues in dealing with climatic variability and change are:

- How will climatic change affect species selection?
- How can trees be successfully established?
- How does climatic variability affect tree growth?
- How will climatic change affect tree growth?

Impacts of climate change on species selection

This project (collaboration between Ensis and the Australian Greenhouse Office, AGO) analysed how climatic change may affect areas suitable for planting particular tree species in Australia. Climate change data from two scenarios for the years 2030 and 2070 were incorporated into a climatic mapping program for Australia. A description of the climatic requirements of any given tree species can be entered into the program and suitable areas identified. The project report analysed climatically suitable areas for 31 species, mainly eucalypts and pines, under present and possible future conditions. It is expected that the report will be released later in 2006.

Successful establishment techniques

A current project (collaboration between Ensis and the AGO) is developing guidelines to help successful establishment of trees under variable climatic conditions. Relevant publications have been reviewed and experienced tree planters are being interviewed across the country. National and regional guidelines will be prepared by the end of 2006.

Impacts of climate variability and change on growth

The analysis of annual growth of *E. globulus* from a large database of permanent sample plots has provided useful insights into the impact of climatic variability, particularly drought. Rainfall in central Victoria was below average for nearly all the nine years for which growth data were available (1996-97 to 2004-05). Tree growth was particularly reduced in 2002-03 when rainfall fell below 500 mm in many areas.

As part of this study (collaboration with the Department of Primary Industries Victoria) the effects of climatic and atmospheric change on *E. globulus* have been examined at three sites (Angustown, Seymour and Kilmore) in the SWGB catchment and five other sites in Victoria (Hamilton, Colac, Ballarat, Benalla and Traralgon). The CABALA model was used as, unlike the 3-PG model, it incorporates the effects of increased concentrations of carbon dioxide on growth.

If the impacts of carbon dioxide are not considered, then it is predicted that there will be slight decreases in productivity at most locations. Using the Cubic Conformal (CC) climate change scenario prepared by CSIRO Marine and Atmospheric Research, the drop in productivity across the eight sites is about 5% in 2030 and 10% in 2070.

However, if the impacts of carbon dioxide are incorporated, it is predicted that there will be increases in growth of about 17% in 2030 and 50% in 2070 under the CC scenario. Growth may increase if 'carbon dioxide fertilisation' effects, associated with increased photosynthesis and water use efficiency, are realised. However, more work is required to determine if such effects will be maintained under field conditions.

Environmental Services

Forests provide environmental services including improved water quality, enhanced biodiversity and carbon sequestration. However, they can also reduce streamflows. Careful locating of new forests can minimize water quantity impacts while maximising environmental outcomes. An important first step in developing tools for targeting and predicting outcomes is to have models for water and salinity impacts, rates of carbon sequestration and biodiversity benefits, verified as much as possible for a range of site and forest conditions. This section describes the research program undertaken to provide underpinning data and the testing of various biophysical models.

Impacts on stream salinity and flows

Regional-scale targeting

Understanding the impact of revegetation on water quantity and quality at regional scale has been undertaken within the SWGB catchment as a case study, and for the whole of the Murray Darling Basin. Both commercial tree plantations and environmental plantings have been considered.

The BC2C (Biophysical Capacity to Change) model was specifically designed by the CRC e-Water to help identify valleys where trees may or may not be used to reduce stream salinity and to provide a first estimate of the salinity reduction that may be achieved (Figure 7). The CEF program has improved predictions for low-medium rainfall areas in the Murray-Darling Basin through calibration to an extensive data set. By including in the SPIF tool the predicted impacts on water and salinity of new plantings, they can be compared to other environmental benefits and so assist in catchment planning.

Figure 7. Map of CEF opportunities in the Murray-Darling Basin: medium-high rainfall areas where afforestation would be expected to lead to reduced catchment salt exports within 15 years after planting (source: CEF/Water for a Healthy Country).

Outputs from the BC2C modelling have demonstrated that targeting of plantations and environmental plantings can markedly influence their impact on salt interception compared to when plantings are not targeted.

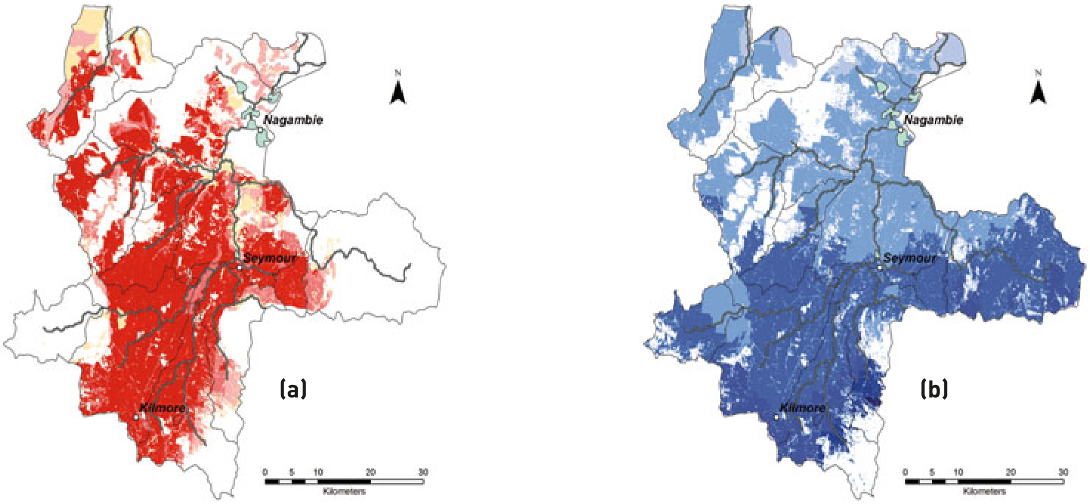


Figure 8. Map of CEF opportunities in the SWGB region: showing spatial differences in the size of the expected impact of afforestation on (a) stream salinity, and (b) catchment water yield.

A well-managed tree planting can strongly reduce soil erosion and river pollution by reducing sediment and nutrients. The SedNet (Sediment budgets for river Networks) model allows catchment managers to identify priority areas for managing these problems. SedNet was developed by CSIRO for Australia's Land and Water Resources Audit. It is able to distinguish between different pathways for pollutant generation and transport to streams, such as surface erosion, gullying and river bank erosion. With this knowledge, the ability of new tree plantings to reduce erosion and pollutants can be estimated. SedNet predictions for the SWGB were incorporated in the SPIF tool, enabling these impacts to be taken into account in planning and assessment of forest plantings.

Once priority areas have been designated, more detailed predictions are often needed. In most cases, it will be important to predict how salinity changes during low water flow and high water flow conditions. Also it can be important to estimate how stream salinity is changed in parts of the river between the planting and the catchment outlet. The ability to predict changed outflows of water and salt at the end of the catchment will enable the evaluation of impacts even further downstream, for example in the Murray River.

The 2CSalt model was developed by the CRC e-Water to provide these predictions and was tested as part of the CEF program. This tool provides more detail than BC2C in that it uses more detailed maps of terrain, soil and land use and predicts monthly changes in flow and salinity over time and along the river network.

Farm-scale targeting

On any property there will be variation in soil depth, soil type, rainfall and climate. These variations are often related to position on the hill slope and can cause differences in tree growth and hence of water use and groundwater recharge. The flow of water over soil during rain storms and afterwards through the soil, known as lateral water redistribution, can create further differences in the amount of water available and used by trees in different positions on the hill slope. In addition shallow groundwater tables in valley bottoms can encourage tree growth and water use, but also lead to increases in soil salinity.

The CEF program developed the FLUSH (Framework for Land Use and Spatial Hydrology) model that predicts the relative increase in forest productivity and environmental benefits that can be achieved through optimising planting design. It requires local information on the relationship between topography, soil properties and climate.

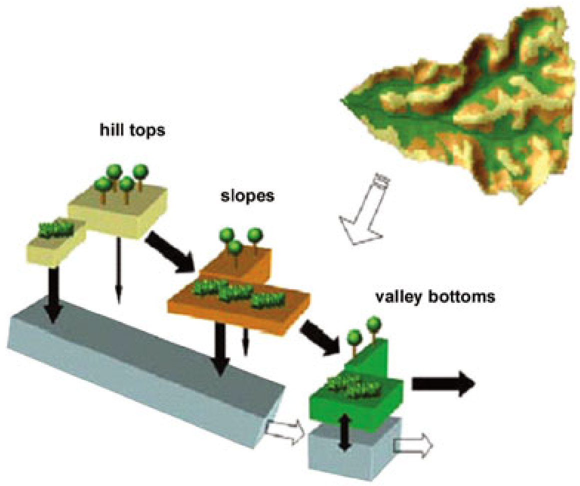


Figure 9. Schematic diagram of landscape components and waterflows simulated in FLUSH

The FLUSH model was linked to the 3-PG+ and 2CSalt models to compare the impacts of revegetation and predicted rates of growth in different positions in the landscape. Importantly, data have been collected to test the model for its accuracy in predicting growth and impacts on stream salinity and water flows. Field work in combination with modelling suggests that spatial water use and growth differences are related primarily to soil water holding capacity in the SWGB. Lateral distribution of water seems to have a limited role in the water balance due to local soil conditions. In other environments, such lateral distribution may play a much more important role. In collaboration with the CRC e-Water, this model will be released later in 2006 through the Catchment Modelling Toolkit.

Environmental plantings and on-farm remnant forests

The BC2C model assumes that, for a given rainfall, all forests have the same impact on streamflow. At a broad level this generic approach is a good first approximation for regional targeting, providing that the model is properly calibrated. However, the reality is that tree species vary markedly in their rates of growth on any given site. Furthermore, a key assumption to date has been that, in low-medium rainfall areas and locations where groundwater or lateral flow is not accessible by vegetation, it is likely that any deep-rooted perennial vegetation established in soils with adequate water holding capacity (or depth) will grow and use most of the available rainfall. However, this assumption remains to be tested.

Good data are available for rates of growth and water use of the traditional industrial plantation species, however there are almost no data for environmental plantings.

The hydrological impact of the various types of environmental plantings and remnant forest in north-central Victoria was assessed, taking into account soil properties, water use, groundwater recharge, and surface runoff. Data were collected for:

- Rates of depletion of soil water,
- Rates of tree transpiration,
- Rainfall, and
- Soil properties.

Site water balances were calculated, including for paired forest-pasture sites, to calibrate the 3 PG+ model for prediction of growth and water use, and then to calibrate BC2C. There were large differences among sites in rates of water use. Reasons for this are still being investigated, but for example, it is likely that site factors such as stand age, soil type and site preparation (ripped or not) play an important part.

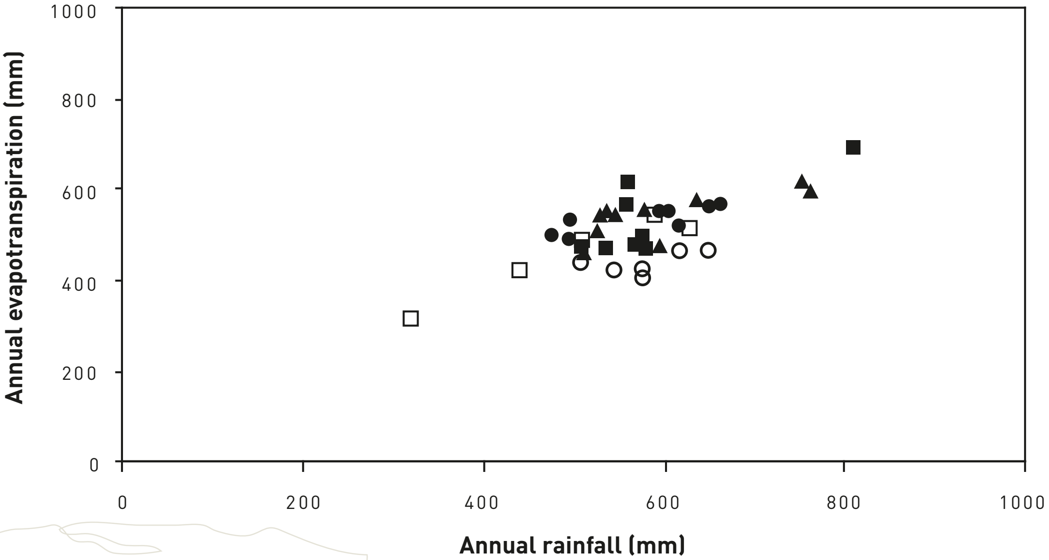


Figure 10. Relationship between annual evapotranspiration (ET) and rainfall (RF) for different vegetation types. Farm Forestry (□) is annual ET and RF for a *E. tricarpa* plantation from detailed measurements made during 2002-06 (11-15 years of age) at a site in Coomalong, Benalla, Victoria, and Grass (○) represents 12 month of measurements of ET and RF for degraded, poorly managed grass at different sites within the SWGB during 2005-06. Annual ET for natural regeneration (■), direct seeded (●) and tubestock (▲) for various sites in the SWGB are estimated as an average for 15 year period using calibrated 3-PG+ model.

Forest management impacts

Management of tree plantations for hydrologic impact depends on an integrated approach to balancing productivity and water recharge control. Consequently, the impacts of thinning *E. tricarpa* (red ironbark) on growth and deep drainage were studied. At age 10 years, three thinning treatments were applied: 900 stems ha^{-1} (no thinning), thinning to 600 stems ha^{-1} and thinning to 300 stems ha^{-1}. Detailed measurements of climate, soil properties, growth and water use were made during the subsequent three years.

Data were used to calibrate the 3-PG+ model for growth and water use of ironbark plantations associated with different stem densities and thinning events. Results (Figure 11) have shown that the timing and degree of thinning can have a large impact on drainage under the plantations, and by implication, on streamflows. Implications for landholders and catchment managers are improved predictions of water use and growth with different thinning regimes.

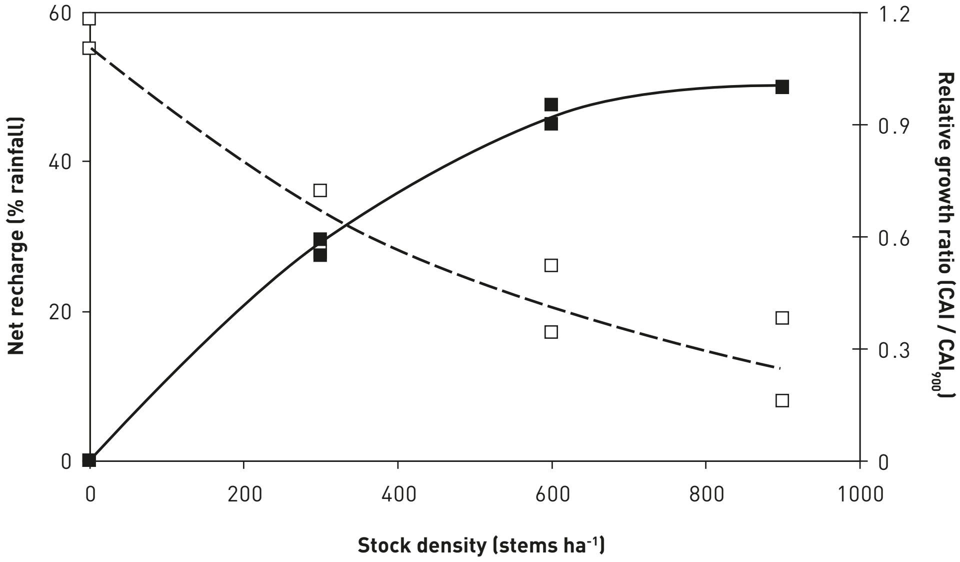


Figure 11. Tradeoff between net recharge and productivity of a 10 year old *E. tricarpa* plantation for three years following three thinning treatments: 900 stems ha^{-1} (no thinning), thinning to 600 stems ha^{-1} and thinning to 300 stems ha^{-1}. Net recharge is defined as the proportion of rainfall that drains below the root zone and is calculated from water balance. Productivity is defined here as the ratio of stem volume growth (current annual increment, CAI) of trees in thinned plots relative to the growth of trees in unthinned plots (900 stems ha^{-1}). Relative growth ratio of trees from 900 stems ha^{-1} treatment is 1.

Biodiversity

The biodiversity impact of industrial plantations can be a contentious issue. Clearly, all forests, be they industrial plantations or native old-growth, provide a range of habitats for conserving and enhancing biodiversity. Quantifying these benefits and providing tools for targeting and assessment of revegetation projects is a key objective.

Plantation Biodiversity Scorecard

The Plantation Biodiversity Scorecard (PBS) was developed to assess the relative biodiversity benefits of a plantation plan or established coupe. This rapid scoring system can be used to assess the habitat values at the planning, management and harvesting stages of any plantation operation in Australia. The score is based on extensive research on the biodiversity values of native forests, commercial plantations and environmental plantings established to specifically improve habitat for native species.

The scoring is based on local site management and landscape characteristics for proposed commercial monoculture plantations validated for *E. globulus*, *E. cladocalyx* and *C. maculata*, and *P. radiata*.
The components of the Plantation Biodiversity Score are summarized in Table 2.

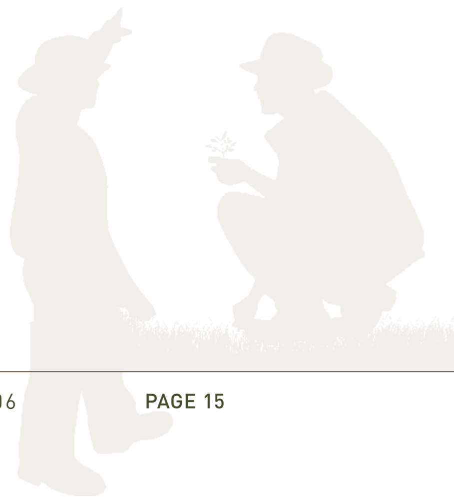


Table 2. The components of the Plantation Biodiversity Score.

Theme	Design Principle	Management Guideline	Max value
Complexity (50 pts)	Structure	1. Incorporate paddock trees	10
		2. Site preparation	10
		3. Preserving biological legacies	10
		4. Install artificial hollows (nest boxes)	5
		5. Thinning and pruning	5
	Time and age	6. Rotation times	5
	Patchiness	7. Mosaics: mixed age stands	5
Composition (10 pts)	Mix of species	8. Mixed plantings	5
	Local species	9. Planting with local species	5
Ecological Management (15 pts)	Weed control	10. Control escapees	5
		11. Control weeds	5
		12. Control animal pests	5
Total Plantation Biodiversity Score at the site scale			**75**
Landscape Scale (25 pts)	Connectivity	13. Measure of connectivity	15
	Width	14. Plantation width	10
Total Plantation Biodiversity Score at the landscape scale			**25**
Total Plantation Biodiversity Score at site and landscape scales			**100**

Habitat values of commercial plantings can be improved by establishing mixed-age stands, increasing rotation length and planting buffers of local native trees, shrubs and grasses. Commercial plantations can include in their plans native stream-side vegetation, or the incorporation of old native trees with hollows and fallen timber. Biodiversity can also be improved by targeting plantations near isolated patches of native forest to improve the movement of native species across the landscape.

Biodiversity in farm forestry, environmental plantings and remnant forests

The biodiversity value of the various types of revegetation programs needs to be properly quantified for decision making purposes. This study measured habitat complexity and bird species richness as indictors of biodiversity in various forest types in north-central Victoria. Surveys of bird species and numbers were undertaken at 38 sites in autumn and spring of 2005 in direct-seeded revegetation, tubestock revegetation, natural regeneration following stock exclusion, remnant forest and farm forestry plantation.

Woodland bird species known to be declining in the region were most strongly associated with the older revegetation sites and remnant woodland sites. A preliminary investigation of potential relationships between biodiversity indicators such as species composition, habitat structure and ecological function, suggests that the bird fauna were most likely to interact with structural features of the habitat (16 interactions, see Figure 12), rather than with functional features such as carbon sequestration (3 interactions). Similarly, carbon sequestration was more likely to be correlated with structural features of the habitat than the bird fauna within (5 interactions). This reflects the possibility of having ecosystems that are highly functional over the short term, without necessarily having a diverse fauna.

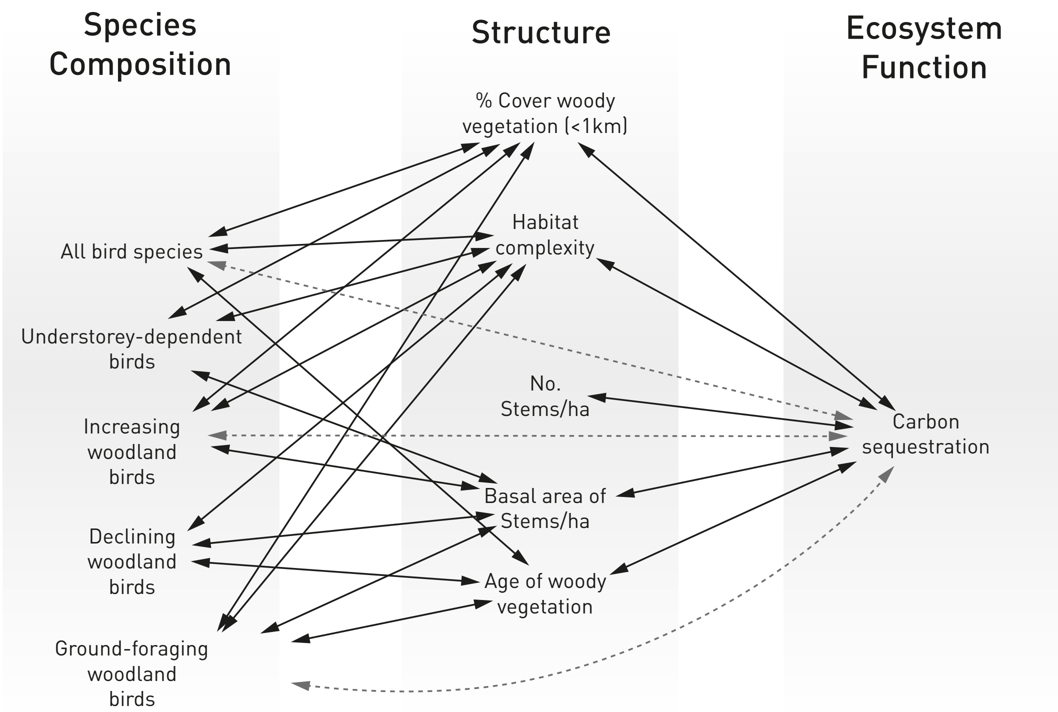


Figure 12. Interactions between bird species composition, habitat structure and ecosystem function, across 38 revegetated and remnant woodland sites between Benalla and Bendigo in north-central Victoria. Dotted lines identify direct relationships between carbon sequestration (functional attribute) and bird groups (compositional attribute).

Carbon sequestration

Verifiable estimation of rates of carbon sequestration in trees is likely to become more important as carbon trading markets emerge and grow. It is important that good information underpins the use of predictive models. There is reasonably good information on rates of growth and carbon accumulation for *E. globulus* and *P. radiata* plantations, but much less data for other types of forests. This study obtained data and calibrated models for several species of commercial interest in low-medium rainfall zones, and for environmental plantings and natural regeneration of on-farm remnants. Biomass data were obtained by destructive harvesting of trees across a range of sites and determining allometric relationships between simple measures of tree size and their biomass and carbon content (see section 'Growth Prediction and Risk' above).

Sugar gum and spotted gum

Initially, rates of growth were predicted from the 3-PG model. The derived allometric relationships were then used to run the FullCAM[1] model to estimate sequestration of carbon by plantations of *E. cladocalyx* and *C. maculata* (Figure 13) in regions of varying mean annual rainfall. Subsequently, rates of carbon sequestration were calibrated to the 3-PG+ model in spatial mode under various management scenarios for input to the SPIF tool.

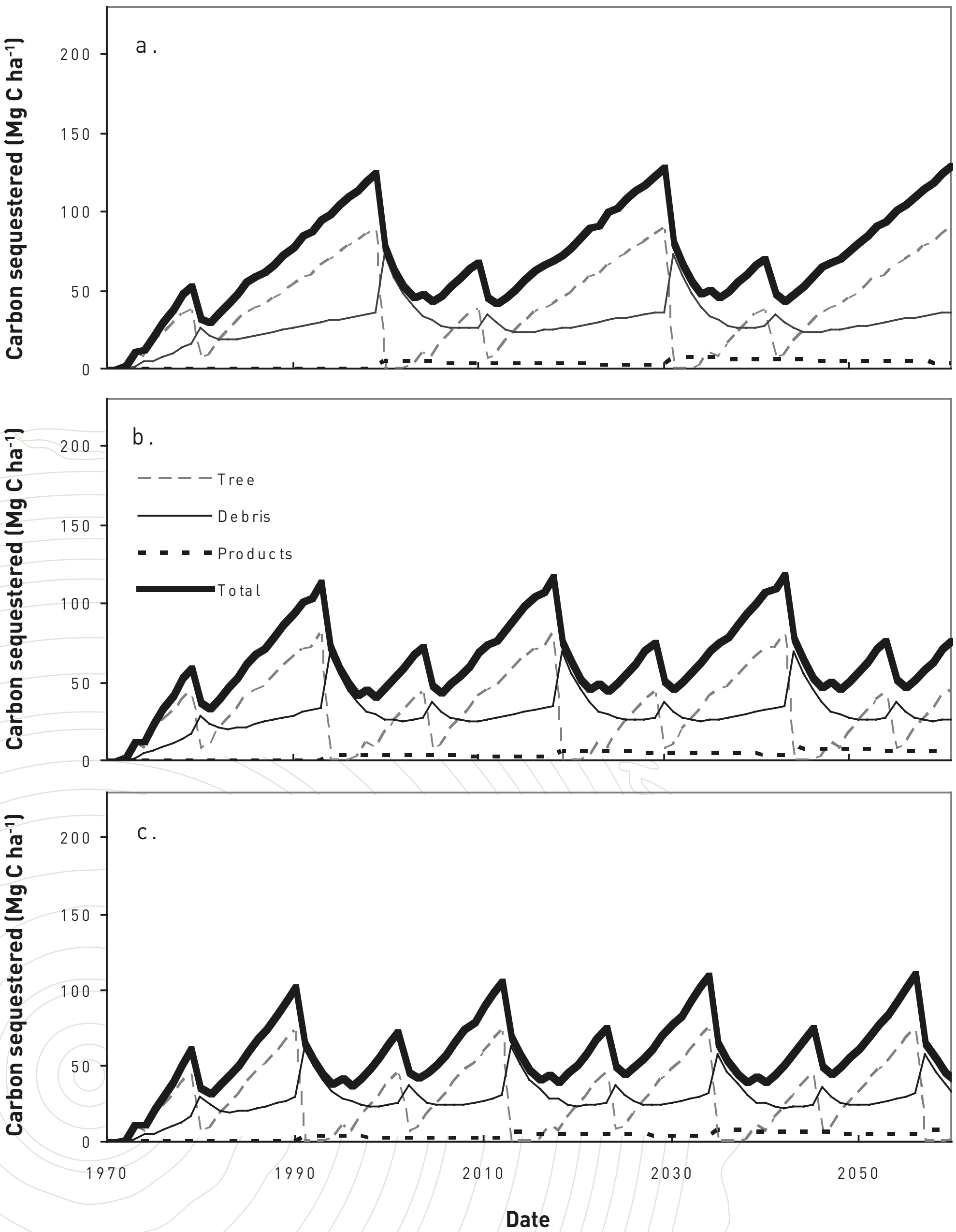


Figure 13. Predicted sequestration of carbon (Mg C ha^{-1}) following establishment of *C. maculata* plantations in (a) low (Angustown, 509 mm and 30-45 year rotation), (b) medium (Seymour, 611 mm and 24-39 year rotation), and (c) high (Kilmore, 755 mm and 21-32 year rotation) rainfall regions of Victoria. Thick black line is total carbon sequestered, grey dash line is carbon sequestered in tree biomass, thin black line is carbon sequestered in debris (litter and dead roots), and black dotted line is carbon sequestered in products, mostly saw logs.

[1]The FullCAM model was developed by the Australian Greenhouse Office in collaboration with CSIRO, the Australian National University and Geoscience Australia. It is the standard model used in Australia's National Carbon Accounting System.

Environmental plantings and on-farm remnant forests

Data were collected as described in the section under 'Growth Prediction and Risk'. Again, data were initially used to calibrate the FullCAM model and later for the 3-PG+ model. Results have shown that excellent calibrations can be obtained for these diverse forest types across a wide range of sites (Figure 14). It is also important for all growth and carbon models to have good site data, especially for the climate and soil depth and type, as these factors affect soil water availability.

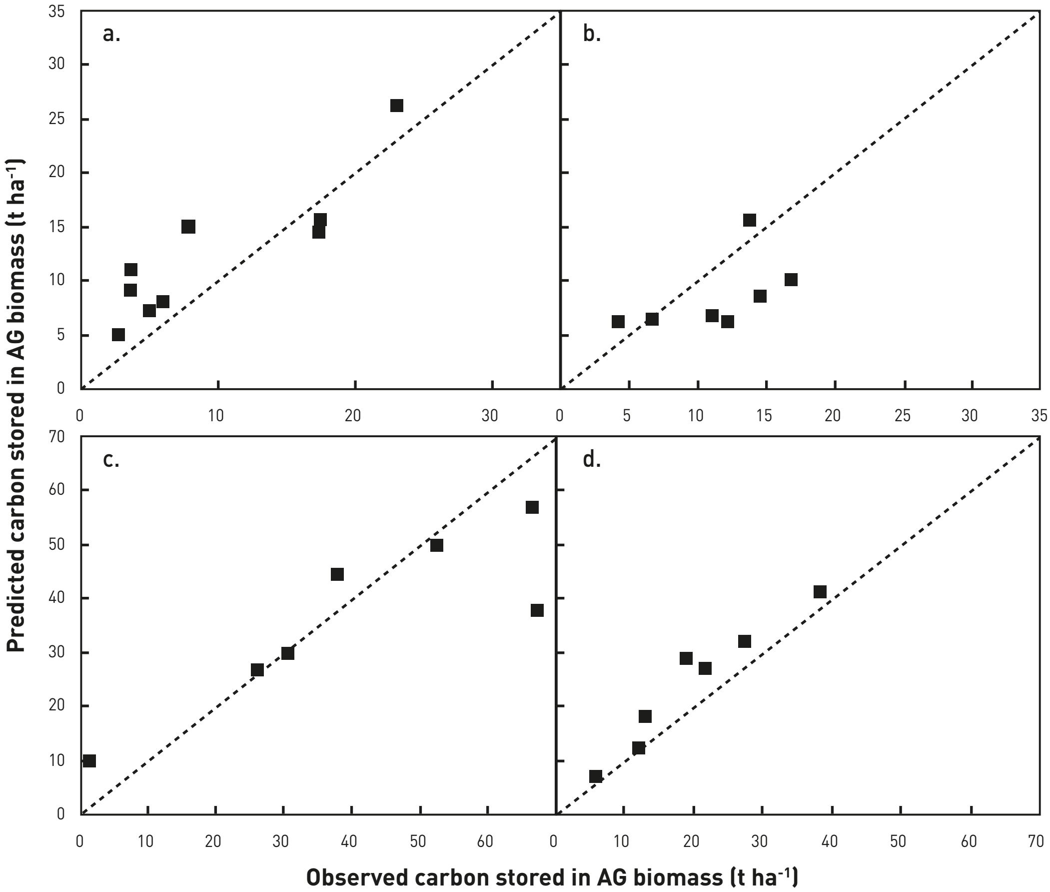


Figure 14. Relationship between observed and predicted (by the FullCAM model) above-ground (AG) biomass (t C ha^{-1}) for a) tubestock revegetation, b) direct seeded revegetation, c) natural regeneration and d) farm forestry. Data points represent individual sites (n=7-9). The dashed line is the 1:1 isoline.

SPIF: The Scenario Planning and Investment Framework tool

The SPIF tool incorporates CEF research outputs into a decision support framework that enables planners at catchment and farm scale to understand and predict outcomes associated with establishment of plantations and other forms of revegetation. The tool enables the user to generate scenarios with different commercial plantations and environmental plantings to determine optimum locations for new forests and the expected environmental and economic outcomes of these plantings.

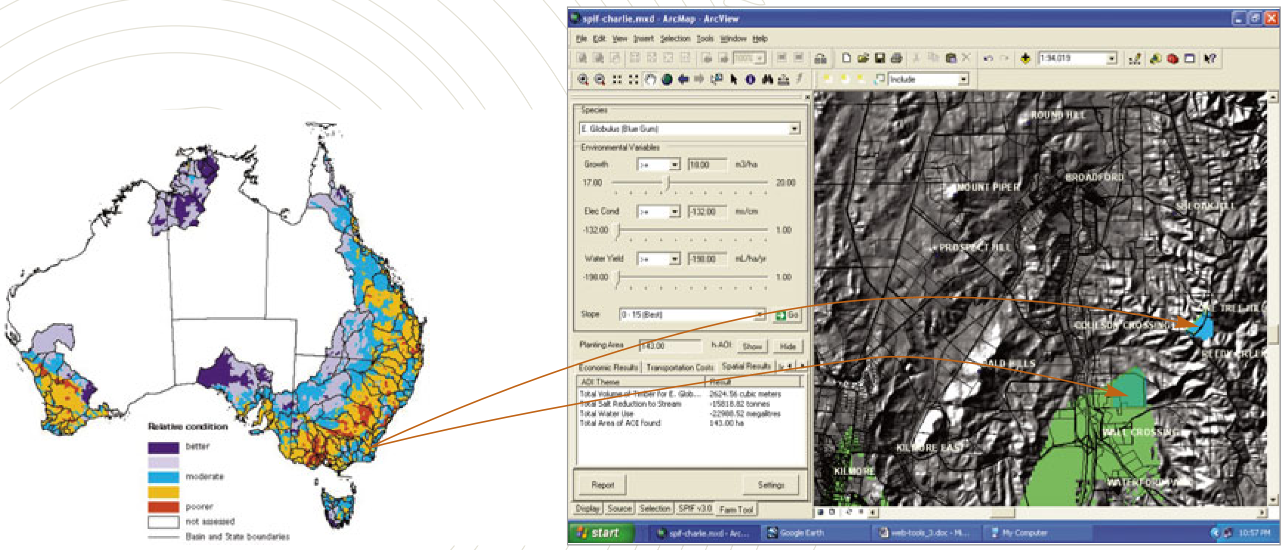
Features and functions

The SPIF tool features the most advanced 3-PG+ calibrations for *E. globulus*, *E. cladoclayx*, *C. maculata*, *P. radiata* and three different classes of environmental plantings and regenerating on-farm native forest.

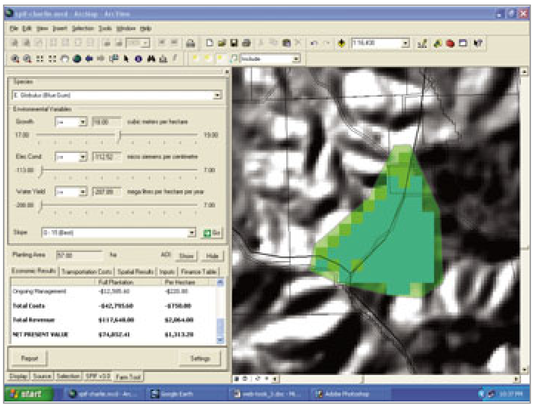
Different workflows provide catchment managers, extension staff, financial planners and other investors in forestry and revegetation with functions to:

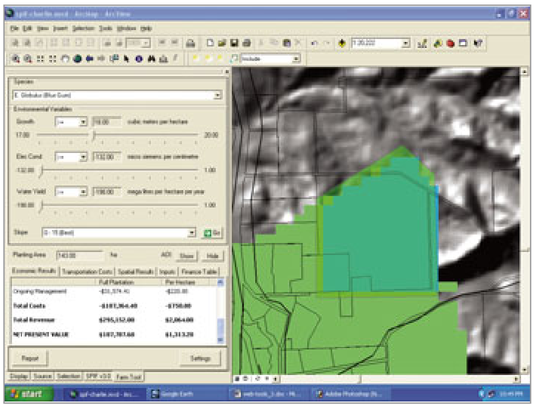
TARGET where to grow within a catchment or on a farm, for:

- Growth
- Carbon sequestration
- Biodiversity enhancement
- Salinity reduction
- Reduced water impacts.

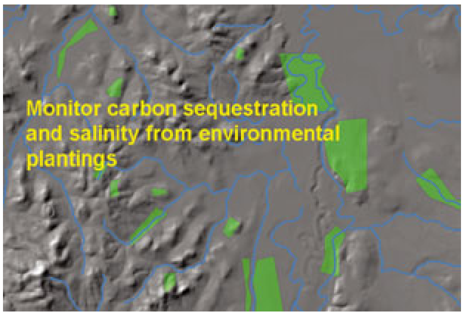


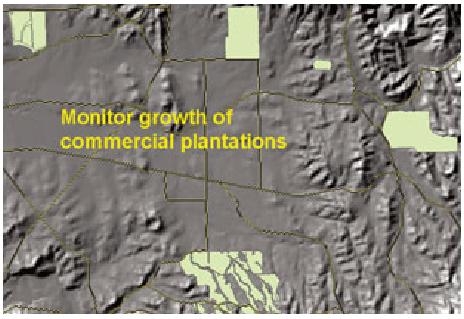
ASSESS project design and expectations.





MONITOR the success of a revegetation program against targets.





The tool is suitable for users such as regional planners or catchment extension officers and can be operated in the field with a farmer or forest planner. The tool was originally developed for ESRI ArcMap but may be customised for other GIS packages or the web.

An example situation of how the SPIF tool might be used would involve a catchment manager producing a map of locations for establishing trees in the landscape to achieve end-of-catchment water quality targets. This would lead to identification of suitable landholders, after which extension officers/financial planners can meet with individuals at their sites to identify and review different forest planting scenarios. Maps can be produced showing optimum locations on their farm for growth, biodiversity and other environmental services, and the relative merits of each option can be assessed. When a decision has been made on the type of planting, plans are submitted to the regional natural resource manager to update their records.

The process of implementing the SPIF tool within a region involves an analysis of the right tree species and planting types to establish for a particular geography given rainfall, soils and morphology of the land. Detailed research is undertaken on trees of local interest. Growth, salt and hydrology models are then calibrated for local conditions and GIS layers developed. The tool is then populated with the new GIS layers and ready for use.

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Better tools to target, assess and monitor commercial and environmental outcomes

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